Engineering, Operations & Technology
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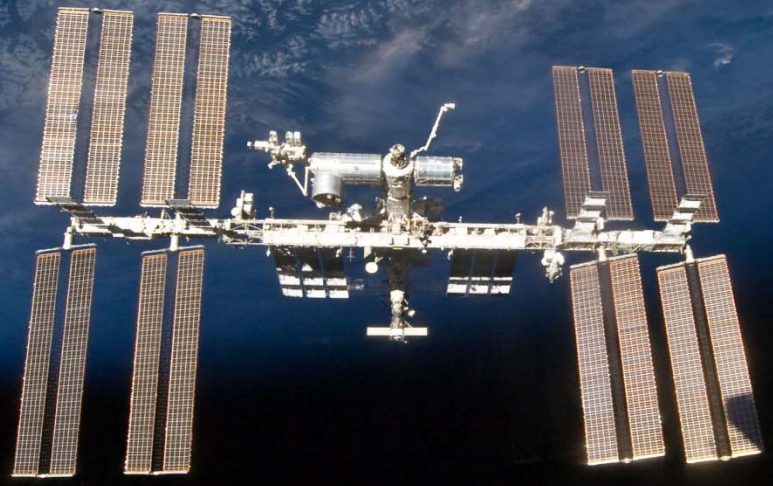
ISS External Contamination Environment for Space Science Utilization



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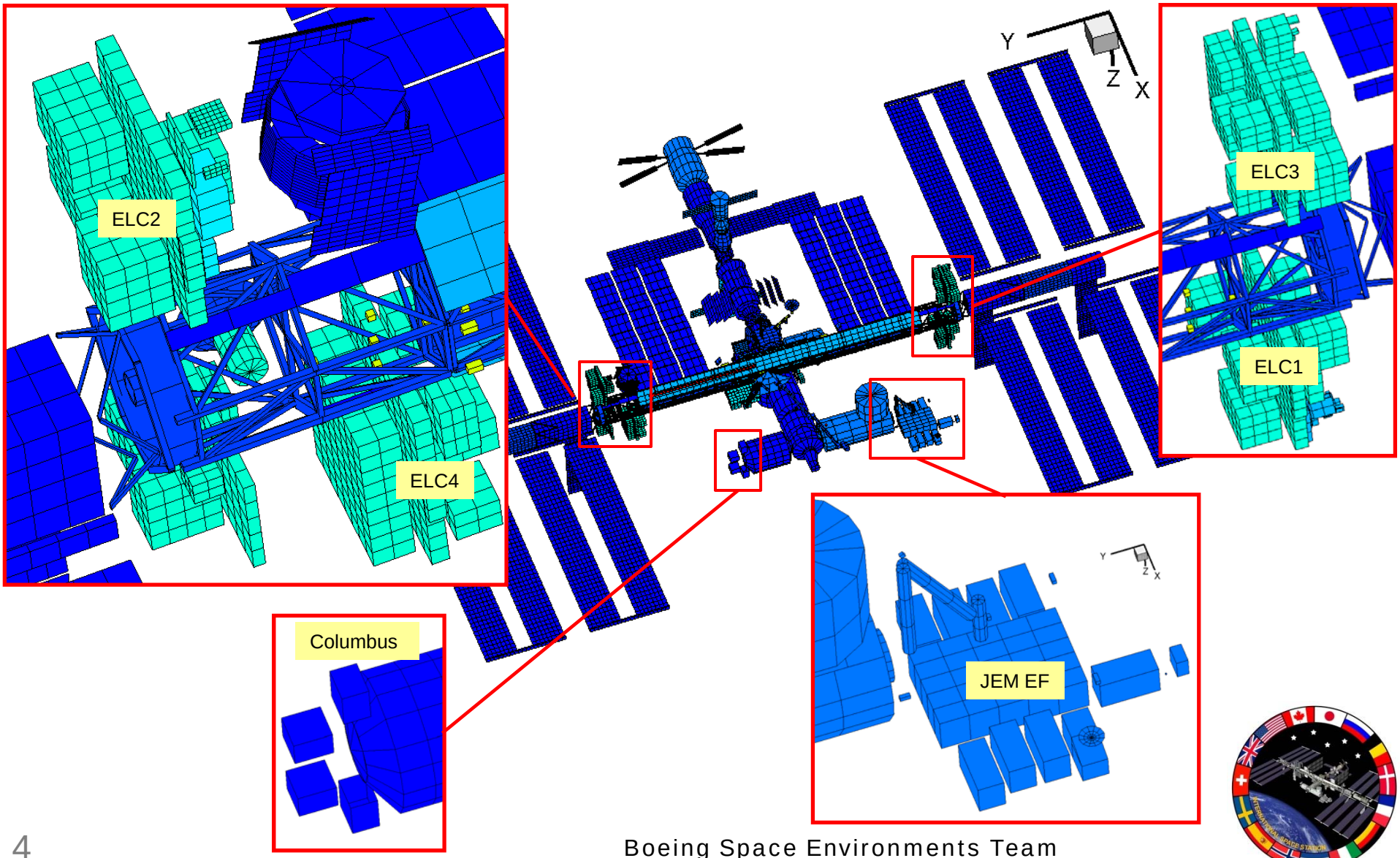
Introduction

- **The International Space Station is the largest and most complex on-orbit platform for space science utilization in low Earth orbit.**
- **Multiple sites for external payloads, with exposure to the associated natural and induced environments, are available to support a variety of space science utilization objectives.**
- **Contamination is one of the induced environments that can impact performance, mission success and science utilization on the vehicle.**
- **The ISS has been designed, built and integrated with strict contamination requirements to provide low levels of induced contamination on external payload assets.**

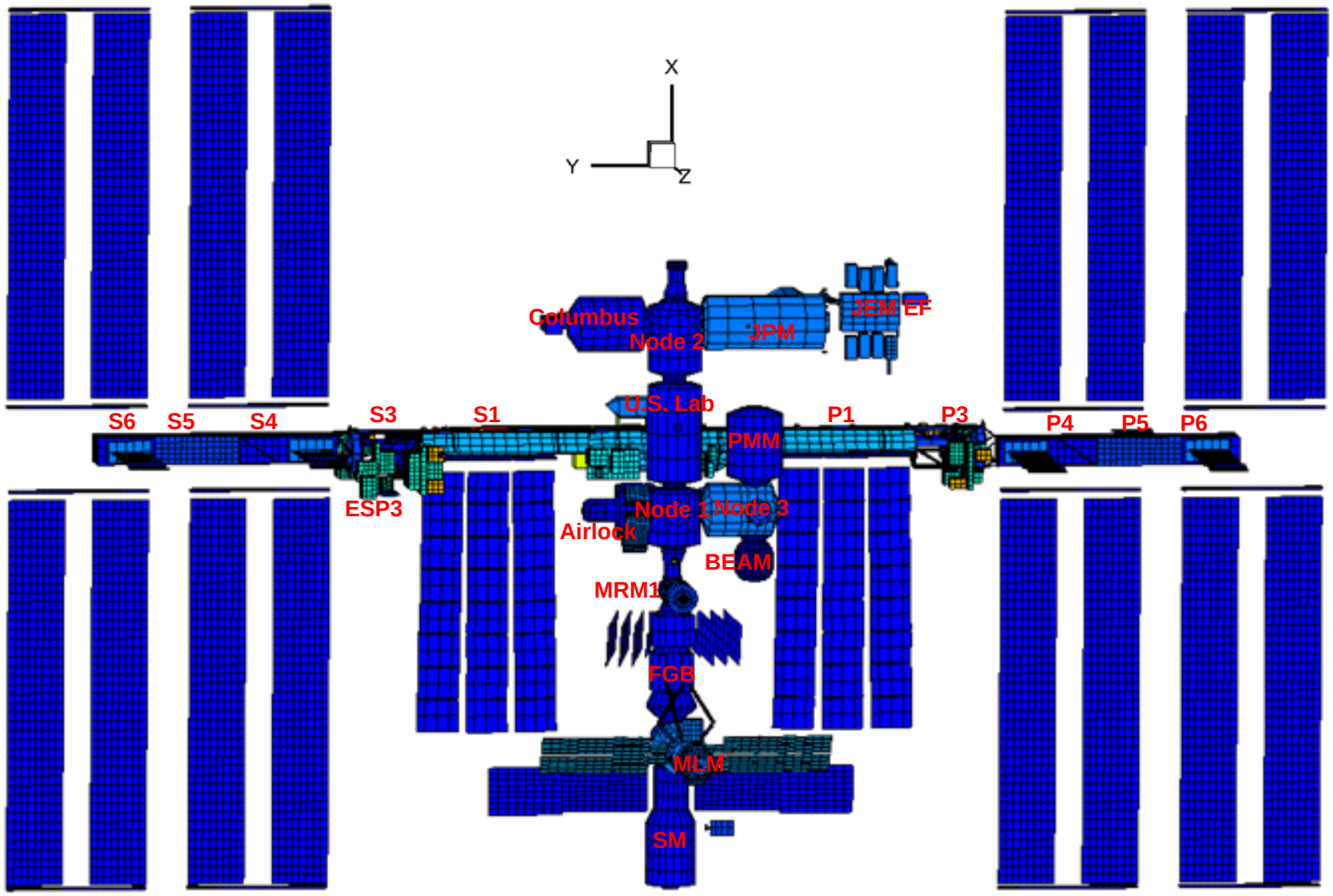
Attached Payloads on ISS

- **Multiple attached payload sites are present on ISS at the port and starboard segments of the U.S. Segment truss, the Japanese Experiment Module, the European Columbus module and on the Russian Segment**
- **Five attached payload sites are present on the truss of the U.S Segment**
- **The Alpha Magnetic Spectrometer 2 (AMS-02) is currently occupying the inboard-zenith site on the starboard side of the truss**
- **An Express Logistics Carrier (ELC) pallet is present at each of the four remaining sites**
  - Each ELC currently provides accommodations for 2 attached payloads plus a complement of ISS spares known as Orbital Replacement Units (ORUs).

Attached Payloads on ISS



ISS Contamination Sources (Nadir View)



Note: Visiting vehicles are not shown.

Boeing Space Environments Team

Requirements

- **System level requirements are contained in the System Specification for the International Space Station (SSP 41000)**
  - Calls on specific sections of the Space Station Contamination Control Requirements, SSP 30426: sections 3.4, 3.5 and 3.6
  - Specify a contaminant deposition limit of 130 Å/year on contamination sensitive surfaces, from all sources of contamination on the vehicle combined
- **ELC Payloads Interface Control Document (ICD) specifies the payload interfaces to ISS and identifies the method of verification, the required verification data inputs and delivery dates**
- **Payloads designed for deployment on the U.S Segment attached payload sites must comply with contamination requirements detailed in SSP 57003, SSP 57003-ELC (for ELC-based payloads), SSP 57004, SSP 57004-ELC (for ELC-based payloads) and SSP 57011**

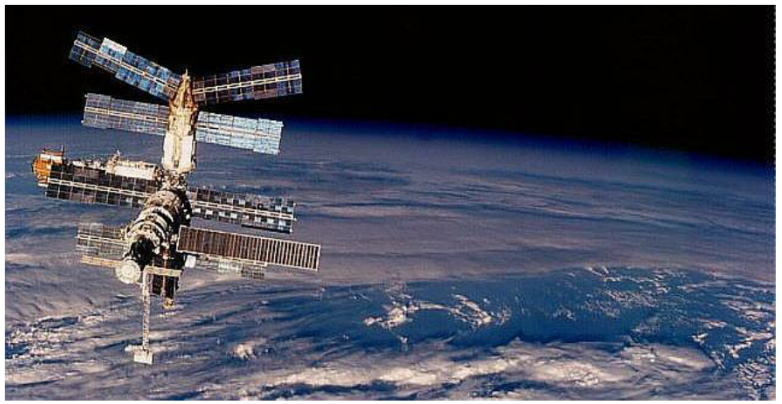
Columbus and JEM-EF Requirements

- **Requirements governing integration and verification of payloads on the European Columbus Module are specified in the Columbus External Payloads Interface Requirements Document (COL-RIBRE-SPE-0165)**
  - Similar to U.S. Segment requirements in principle, but differ on payload-to-payload induced contamination sub-allocations. (The Columbus exposed facility has a different payload topology than the U.S. ELCs.)
- **Payloads flying on the Japanese Experimental Module Exposed Facility (JEM-EF) are governed by the Exposed Facility/Payload Standard Interface Control Document (JPAH Vol. 3, NASDA-ESPC-2563)**
  - JEM-EF requirements specify compatibility with the ISS system level requirements but do not make specific sub-allocations for payload-to-payload induced contamination level within the JEM-EF
  - JAXA conducts contamination analyses to ensure successful integration of payloads within the JEM-EF

ISS Contamination Environment

- **System level requirement specifies a contaminant deposition limit of 130 Å/year on contamination sensitive surfaces**
  - Analyses are performed to integrate all ISS hardware elements and verify that the system level contamination control requirements are maintained for ISS payloads
- **Predicted contamination levels at ISS payload sites are lower than the system level specification for select surfaces**
  - Several contamination sensitive payloads have relied on predicted levels in operational planning
- **Contaminant deposition measurements have been made on returned hardware and comparisons to analysis predictions have been made to assess performance against expectations**
- **Active monitoring of the induced contamination environment on ISS is not yet available**

Summary of Mir Observations

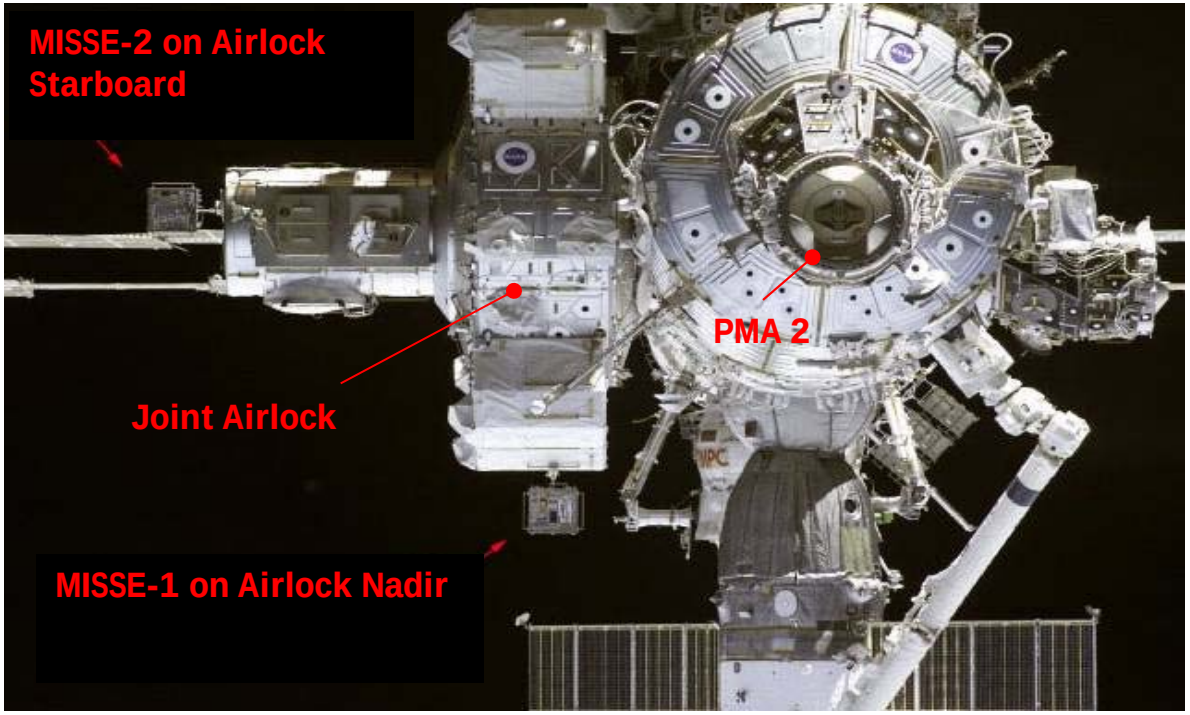


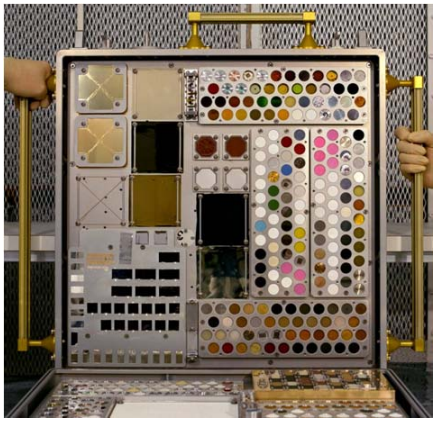
Mir External Contamination Observations

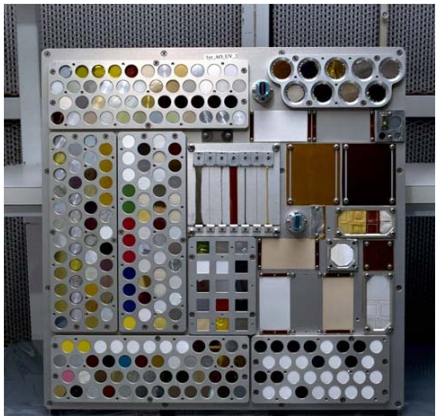
➢ Comes-Aragatz (CNES)	350 - 780 Å	in 13 months
➢ Camera Bracket (NASA)	12,000 Å	in 4 months
➢ ICA QCM 1 (ESA)	13,000 Å	in 3 months
➢ ICA QCM 2 (ESA)	14,500 Å	in 3 months
➢ ICA QCM 3 (ESA)	4,500 Å	in 3 months
➢ Trek Blanket (NASA)	> 20,000 Å	in 4.2 years
➢ Astra-II (RSC-Energia)	5,000 Å	in 13 months

Predictions & Correlations with Measurements: MISSE

- **Returned materials samples from MISSE flight experiment confirmed low levels of induced contamination from U.S. Segment hardware**

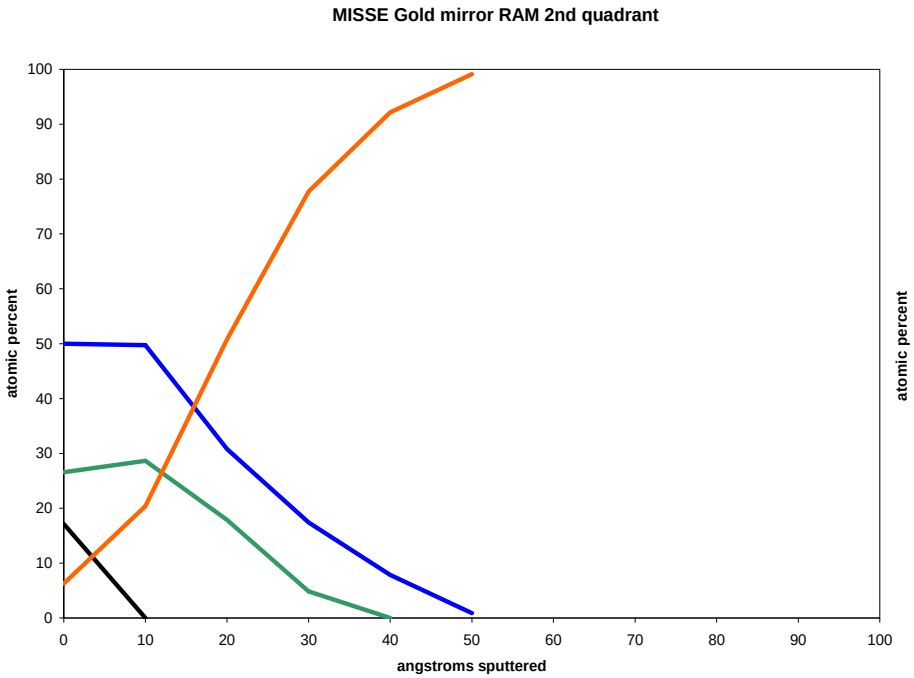




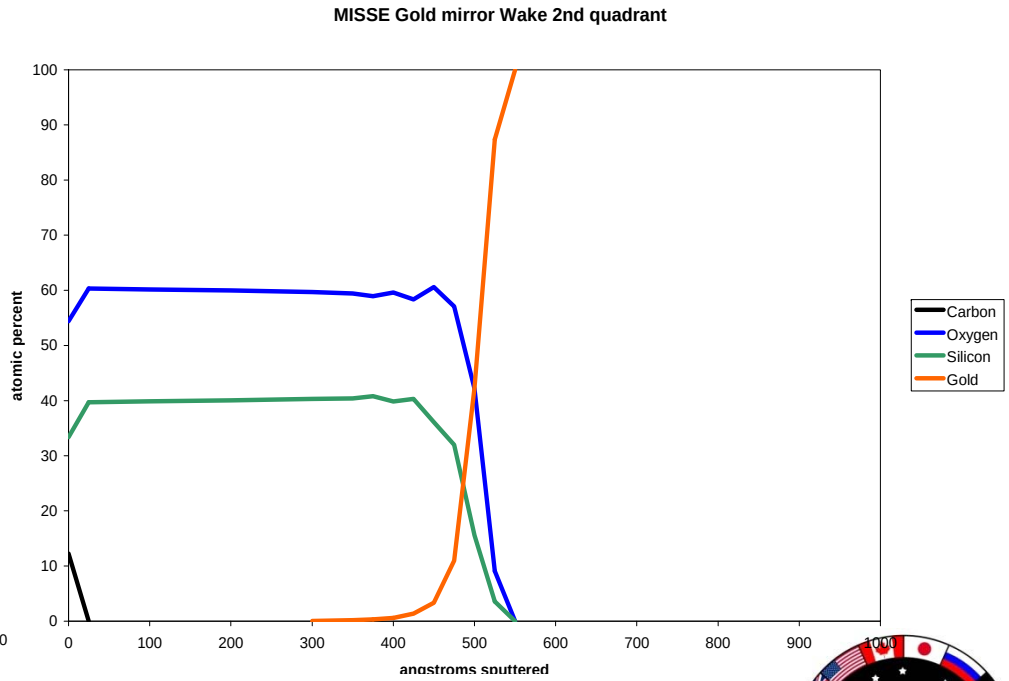


Predictions & Correlations with Measurements: MISSE

- **ISS induced contamination levels on MISSE were measured on ram and wake facing MISSE gold mirrors (WR 200802140)**
  - Measured wake facing mirror contamination was less than 500 Å
  - Measured ram facing mirror was less than 50 Å



MISSE 2 Ram Facing Mirror XPS Results



MISSE 2 Wake Facing Mirror XPS Results

Predictions & Correlations with Measurements: MISSE

- **Excellent agreement between predicted and measured contamination results for the 4.0-year flight**

Experiment	Side	Predicted	Measured
MISSE 2	ram	80 Å	50 Å
	wake	730 Å	500 Å

  - Dominant contamination source for ram surfaces is Orbiter
  - Dominant sources for wake surfaces are FGB and docked Soyuz vehicles

Predictions & Correlations with Measurements: MISSE

- **Ram facing measurements are significantly lower (almost one order of magnitude) than the ISS system level specification limit (equivalent to 520 Å for four years of exposure).**
- **Wake facing measurements were close to the 520 Å limit (for 4 years of exposure) and a result of contamination sources on the Russian Segment that were deployed prior to MISSE 2 installation on the U.S. Airlock.**
- **MISSE-1 and 2 locations on the Joint Airlock were not originally planned for external payload deployment on ISS and hence, not tracked and protected as contamination sensitive locations.**

Observations from Payloads

- **Observations from external payloads on ISS have been positive. Several payloads (e.g., MISSE 1-8 and RAIDS) have reported no indication of significant performance degradation from induced contamination.**
- **A single payload, the European SOLACES experiment (part of SOLAR which is on the Columbus module), observed a significant reduction in counts from its channel electron multipliers (channeltrons) and initially listed contamination as a potential cause.**
- **ISS Space Environments Team conducted an investigation on the causes of the observed degradation eliminating contamination as a cause of degradation and concluded that aging of the SolACES channel electron multipliers was the cause of the degradation (channeltrons have a limit on accumulated counts over their lifetime).**

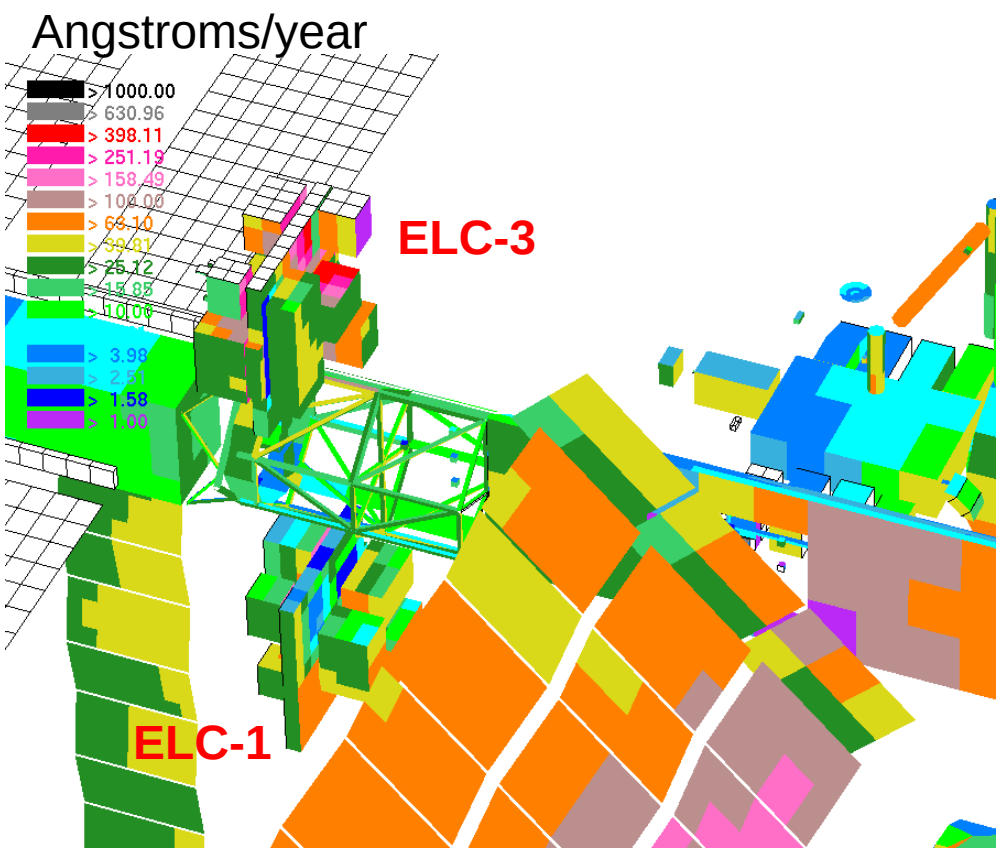
Total ISS Visiting Vehicles Plume Induced Contamination to SolACES Site on Columbus

		Flights per Year							
		2008	2009	2010	2011	2012	Total flights	Å/flight	Total Å
Visiting Vehicles	Shuttle	3	4	3	3	0	13	0.08	1.0
	ATV	1	0	0	1	1	3	0.00	0.0
	HTV	0	1	0	1	1	3	0.05	0.1
	Dragon	0	0	1	0	2	3	0.00	0.0
	Progress/Soyuz (on MRM2)	0	0	3	2	3	8	0.09	0.7
									1.9

- **Total accumulated SolACES site thruster plume induced contamination over a 5 year period (from deployment) is on the order of 2 Å.**
- **These levels of plume contamination are inconsistent with the inferred levels needed to induce degradation.**
- **No plausible path from external contamination sources to inside SolACES to account for the observed degraded spectrometer signals.**

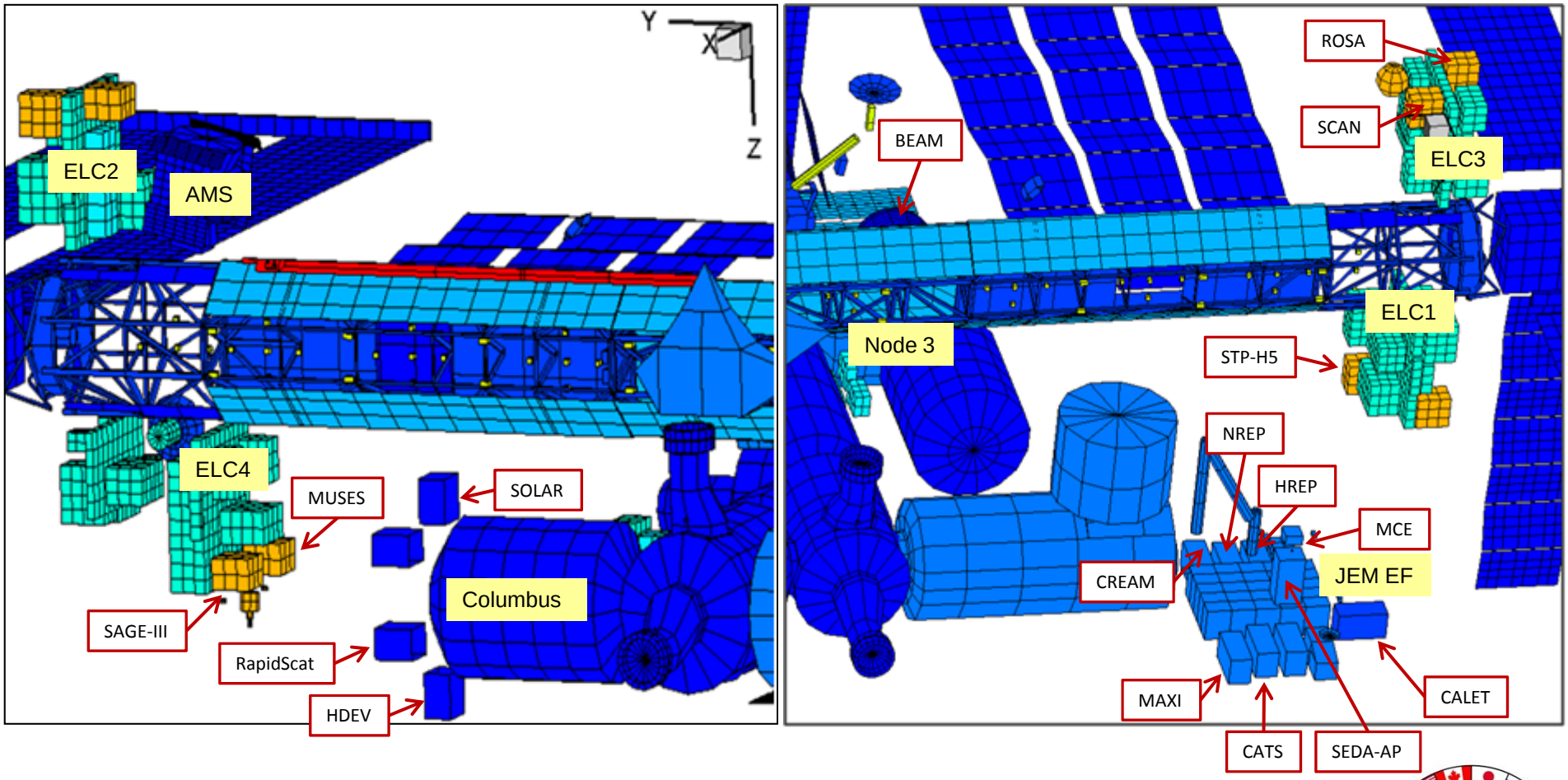
Contamination Mapping

- **As part of ISS payload integration activities, contamination forecast maps are being generated for U.S. attached payload sites to support payload feasibility, topology and placement studies.**



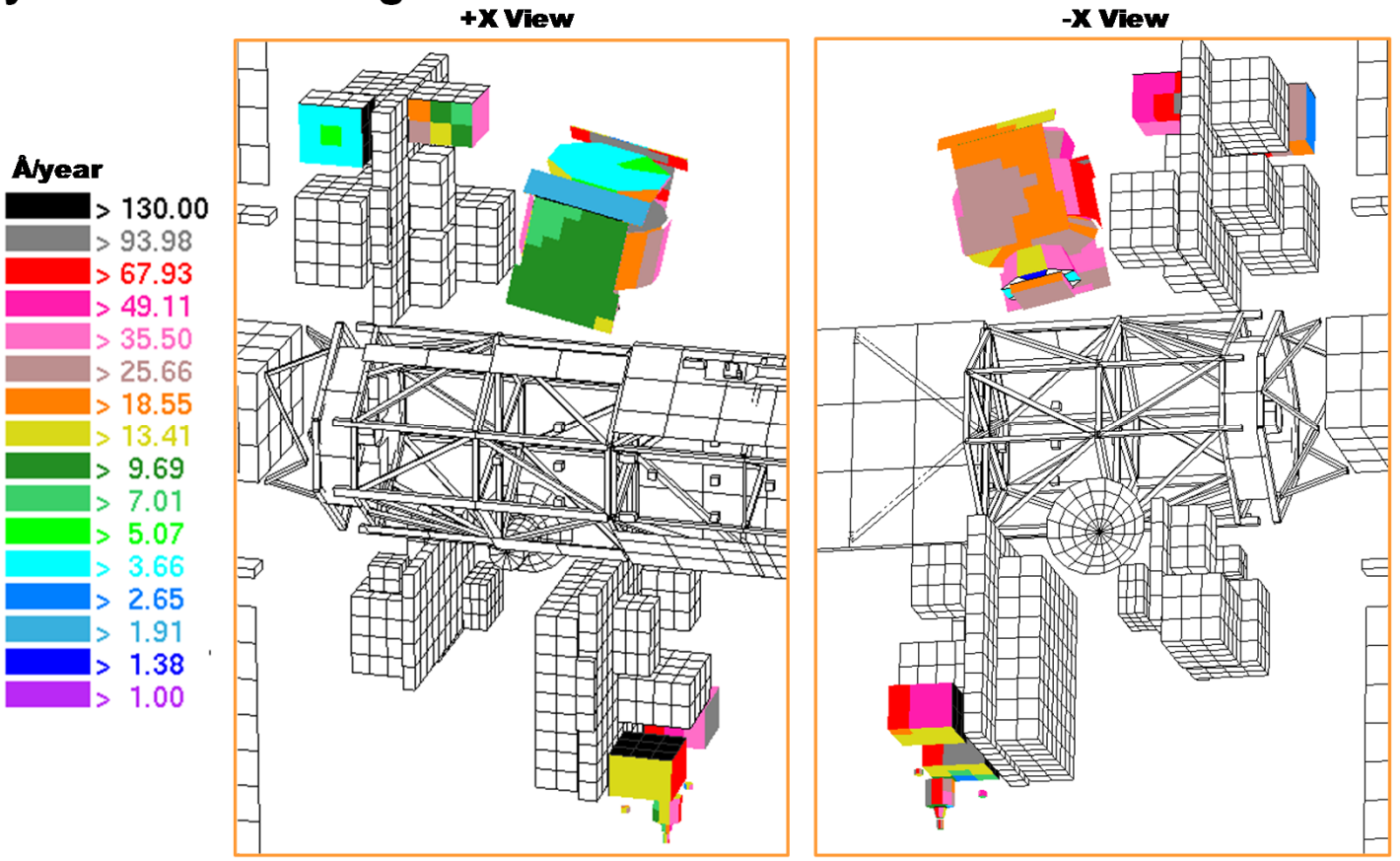
HTV-3 Mission Annualized Contamination from Outgassing

ISS Payloads in 2015



Contamination Mapping

- **ELC-4 will host two highly sensitive Earth science payloads, SAGE-III and MUSES. This forecast map covers 2015 annualized contamination from all sources of materials outgassing.**
- **Similar forecast maps are being generated for future timeframes to support payload manifesting decisions.**



Concluding Remarks

- **The ISS has been designed to offer low levels of induced contamination to its external payload complement.**
- **Multiple science payloads introduce complex induced contamination environment interactions that are accounted for and support successful integration of the ISS payload complement.**
- **Unique analytical capabilities have been developed for the ISS Program to support requirements validation, integration and to forecast contaminant deposition levels on the vehicle.**
- **Contaminant deposition measurements are made on returned hardware and comparisons with analytical predictions are made to assess performance against expectations.**
- **Measurements made on returned hardware show that contaminant deposition levels were within the system level specification and in excellent agreement with predictions.**
- **These activities ensure success of ISS as a platform for space science payloads in low Earth orbit.**

Backup

Attached Payloads Interface Requirements

- **Requirements from SSP 57003, "Attached Payload Interface Requirements Document" are applicable at the integrated ELC level**
  - Section 3.5.1.5.2.A limits a payload site's contribution to surface contamination of another payload site in the form of molecular deposition via materials outgassing and venting to 1E-14 g/cm^2/s [30 Å/year]
  - Section 3.5.1.5.2.B limits a payload site's contribution to surface contamination of sensitive ISS surfaces in the form of molecular deposition via materials outgassing and venting to 1E-15 g/cm^2/s [3 Å/yr]
  - Section 3.5.1.5.3 limits a payload site's active venting release of particulates to only particulates less than 100 microns in size
  - Section 3.5.1.5.1 limits the molecular column density due to venting, leakage and outgassing of a payload site from exceeding along any unobstructed line of sight a value of 1E+14 molecules/cm^2 for any individual species

Attached Payloads Interface Requirements

- **Requirements from SSP 57003-ELC, "Attached Payload Interface Requirements Document" are applicable at the integrated ELC level**
  - Section 3.5.1.5.2.A limits a payload site's contribution to surface contamination of another payload site in the form of molecular deposition via materials outgassing and venting to 5E-15 g/cm^2/s [15 Å/year]
  - Section 3.5.1.5.2.B limits a payload site's contribution to surface contamination of sensitive ISS surfaces in the form of molecular deposition via materials outgassing and venting to 5E-16 g/cm^2/s [1.5 Å/yr]
  - Section 3.5.1.5.3 limits a payload site's active venting release of particulates to only particulates less than 100 microns in size
  - Section 3.5.1.5.1 limits the molecular column density due to venting, leakage and outgassing of a payload site from exceeding along any unobstructed line of sight a value of 1E+14 molecules/cm^2 for any individual species

Attached Payload Interface Requirements

- **SSP 57004, “Attached Payload Hardware Interface Control Document Template”, and SSP 57004-ELC, “Attached Payload Interface Control Document – ELC Cargo Interface Control Document Template”, includes deadlines and actions a payload developer must support for satisfactory closure of verification requirements**
- **Analyses are performed to assess compliance with the requirements documented in SSP 57011, Payload Verification Program Plan, and to ensure that the complement of payloads meets ISS interface requirements**
- **The payloads are assessed at the element level as well as the ISS system level**

Verification Data Deliverables

- **Payload developers deliver a characterization of contamination sources on their payloads**
  - Vacuum exposed materials (all non-metallic materials outside of a pressurized or hermetically sealed environment)
  - Vacuum venting (liquids and gases)
  - Leakage
  - Thrusters
  - Sources of particulate releases
- **Identification of contamination sensitive surfaces on the payload is also required**
  - This data is used to track induced contamination on the payload from the vehicle (ISS), visiting vehicles and other payloads

Materials Outgassing

- **Required data for all non-metallic vacuum exposed materials**
  - Material identification
  - Location of application on payload
  - Vacuum exposed surface area
  - Nominal operating temperature range
  - Outgassing rate data from ASTM E1559 testing
- **The preferred format for the definition of operating temperature data for payload materials is one that specifies the percentage of time spent under 30°C, between 30° C and 60°C, and between 60°C and the maximum operating temperature**
  - This type of definition removes excessive conservatism from the analysis when compared to an analysis using only maximum operating temperature data

Outgassing Rate Data

- **Outgassing rate data from ASTM E1559 testing is required to support induced contamination analysis**
- **Testing for the ISS Program is based on Method B of the ASTM E1559 standard**
  - Minimum test duration of 144 hours
  - Four Thermally-controlled Quartz Crystal Microbalances (TQCMs) are used for condensable outgassing rate measurements
    - TQCMs are held at 80K, -40° C, -10° C and +25° C
    - Selection of these temperatures was based on the operating temperatures of ISS contamination sensitive surfaces which include active and passive thermal control system radiators, laser retro-reflectors, windows, sensors and science payloads

Verification Data Submittals

- **Preliminary verification data deliverable is required 24 months prior to launch (L-24 months) with preliminary characterization of contamination sources**
  - The preliminary data delivery at L-24 months is used to identify potential issues and allow for corrective action with minimal impacts to cost and schedule of payload development and integration
- **An update to the preliminary data delivery is required if significant sources of contamination (or significant changes) are introduced prior to final data delivery**
  - The same principle applies to updates; analysis results are used to indentify potential issues
- **Final verification data submittal is required 7.5 months prior to launch (L-7.5 months)**
- **The final analysis reports supporting verification are issued by L-3 months**

Integration and Verification Workflow